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COMMISSION OF THE EUROPEAN COMMUNITIES

A SLIDE RULE FOR THE EVALUATION OF GEOCHEMICAL AND MINERAL SURVEY DATA

by

H. I. DE WOLDE and J. W. BRINCK

1971

Joint Nuclear Research Centre
Ispra Establishment - Italy
Scientific Information Processing Centre - CETIS
and
Directorate-General Energy

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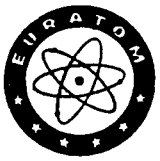

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ABSTRACT

The geochemical slide rule has been developed as a simple calculating aid to the economic geologist and mineral survey data in terms statistic evaluation of geochemical- and mineral survey data in terms of mineral resources and possible ore reserves.

The rather complicated formulas which describe the theory on the log-normal distribution of minerals in the earth's crust as developed by one of the authors, can be numerically applied easily by the slide rule.

KEYWORDS

EVALUATION
GEOCHEMISTRY
MINERALS
ECONOMICS
GEOLOGY
EXPLORATION
STATISTICS
DEPOSITS
EARTH CRUST
URANIUM

CONTENTS *)

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*) Manuscript received on 10 November 1970

1.- THE GEOCHEMICAL SLIDE RULE has been developed as a simple calculating aid to the economic geologist and mineral explorer for the statistic evaluation of geochemical- and mineral survey data in terms of mineral resources and possible ore reserves.

2.- MINERAL RESOURCES is a term denoting the purely factual concept of the total tonnages of an element, available at different concentrations of any given individual size, in a given geological environment.

3.- MINERAL RESERVES is an expression for the actually measured concentrations of known grade and size. They are divided into:

1) ore reserves from which the element can be extracted with a profit
2) potential ore reserves from which the mineral could be extracted at a profit at a higher than current price or with improved technology.

Depending on the accuracy of the estimation, the mineral reserves are classified:

1) Proven reserves
2) Probable reserves
3) Possible reserves.

4.- THE LOG-NORMAL DISTRIBUTION of the element concentrations is the basic concept of the described theory and the applied calculations:
The weighted frequencies of the logarithm's of the element concentrations, estimated from a series of regionally related samples, can be fitted into a normal probability distribution.
This observation appears to be largely independent of the size of the individual samples.
The validity has been proved in respect to surveys, in which each sample represents millions of tons of rock, as well as in mine evaluation in which each sample represents a few tons of rock. The particular distribution of ore deposits in the earth's crust in which elements concentrations of relative small size may group together to form ore deposits which in turn may form a mineral district or even a mineral province, also has been attributed to this log-normal distribution of element concentration in the earth's crust (Brinck 1967).

5.- THE ESSENTIAL CONDITIONS for the validity of the log-normal interpretation of the element distributions are:

a. the individual samples should be small in respect to the sampled environment
b. the individual samples should be large in respect to the grain size.

Other factors limiting the validity of the log-normal interpretation, such as composite distributions or overflow conditions (the estimated concentration is of the order of the element content in the most common mineral form, oxide, sulfide, etc.), will not be discussed here.

6.- THE MEDIAN CONCENTRATION γ of a log-normal distribution is given by:

$$\log \gamma = \frac{\sum_{i=1}^{N} w_i \log x_i}{\sum_{i=1}^{N} w_i} \qquad [1]$$

in which: N is the number of samples
x_i is the element concentration in sample i
w_i is the weight of sample i.

7.- THE STANDARD DEVIATION σ is given by:

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} w_i \left[\log x_i - \log \gamma\right]^2}{\left[N-1\right] \sum_{i=1}^{N} w_i}} \qquad [2]$$

The standard deviation is a measure of the dispersion of the concentrations around the most frequent or median value γ for the average sample size $\bar{w}$:

$$\bar{w} = \frac{\sum_{i=1}^{N} w_i}{N} \qquad [3]$$

8.- THE AVERAGE CONCENTRATION $\bar{x}$ may now be calculated by:

$$\bar{x} = \gamma . e^{\frac{1}{2}\sigma^2} \qquad [4]$$

It must be well understood that by sampling a certain environment, the

median γ and the standard deviation σ depend on the sample weights, in contrast with the average $\bar{x}$ which is an absolute value.

9.- THE PROBABILITY OF OCCURRENCE P of a concentration $\geqslant x_k$ with size $\bar{w}$ in the sample environment R may be calculated by:

$$\log x_k - \log \gamma_R = \sqrt{2}\ \mathrm{ERF}^{-1}\left[1-2.P_k\right].\sigma \qquad [5]$$

or:

$$P_k = 0.5 - 0.5\ \mathrm{ERF}\left[\frac{\log x_k - \log \gamma_R}{\sqrt{2}.\sigma}\right] \qquad [6]$$

Therefore the probably available total tonnage r_k of all concentrations $\geqslant x_k$, with an average weight $\bar{w}$, in the environment R can be estimated:

$$r_k = P_k.R \qquad [7]$$

10.- THE DIMENSIONS OF R, r AND w are volumetric units. If the specific gravity of the r_i may be expected to be more or less equal to the specific gravity of R, weight units can be used.

11.- THE ABSOLUTE DISPERSION COEFFICIENT α has been defined to describe the probability of occurrence of concentrations of other weights than $\bar{w}$ (see paragraph 9), in relation to the sample distribution. The formula of Matheron-De Wijs introduces the absolute dispersion coefficient α:

$$\alpha = \frac{\sigma^2}{3 \log \frac{D}{d}} \qquad [8]$$

in which D and d respectively are the linear equivalents of the sampled environment and of the average sample (Matheron 1964, Carlier 1963). The estimation of D and d will be described in paragraph 12.
This relation has been defined to compare the absolute grade contrast in different mineral deposits. It could equally be used for the comparison of geochemical survey results from different geological environments. In a very simplified way one might consider α as a special kind of standard deviation independent of the sampling method. It is an absolute fractional value ($0 \leqslant \alpha \leqslant 1$) directly related to the specific mineralizability of a given element in the environments.

Of course the accuracy of estimation of α increases with increasing sampling as does the average $\bar{x}$ of the environment R.

12.- THE LINEAR EQUIVALENT d has been described by Matheron. For the more exact derivation we must refer to the original paper. An approximation may satisfy our goals: The linear equivalent of a volume with the dimensions a > b > c is roughly equal to:

$$d = a + b + c \qquad [9]$$

Generally a volume of a deposit is given by the ratios b/a, c/b and its content V. The linear equivalent d can be calculated by:

$$a = \sqrt[3]{\frac{V}{\left[\frac{b}{a}\right]^2 \cdot \frac{c}{b}}} \qquad [c \neq 0] \qquad [10]$$

$$d = a\left[1 + \frac{b}{a} + \frac{b}{a} \cdot \frac{c}{b}\right] \qquad [11]$$

The linear equivalent of a surface S:

$$a = \sqrt{\frac{S}{\frac{b}{a}}} \qquad [c = 0] \qquad [12]$$

$$d = a\left[1 + \frac{b}{a}\right] \qquad [13]$$

13.- A CONDENSATION OF FORMULAS (4), (6) and (7) is given by the expressions:

$$\left.\begin{aligned} \alpha &= \frac{100 \cdot \log^2\left[\frac{x_k}{\gamma_R}\right]}{6 \log\left[\frac{D}{d}\right] \cdot \left[ERF^{-1}\left[1 - 2 \cdot \frac{r}{R}\right]\right]^2} \ \% \qquad [14] \\ \frac{\bar{x}}{\gamma_R} &= EXP\left[\frac{0.03}{2}\alpha \cdot \log\frac{D}{d}\right] \quad [\alpha \text{ in } \%] \qquad [15] \end{aligned}\right\}$$

Reminding that the distribution of element concentrations of any size and grade is given by the parameters $\bar{x}$ and α, one may reconstruct the whole distribution curve, with the aid of the expressions (14) and (15), out of a known extreme part as for example the largest high grade ore deposit or the collection of all known ore deposits.

A second use is the comparison of geochemical surveys, in each stage, on limited areas, with world figures.
Also the economic geologist on raw materials may use these expression to calculate probable ore reserves at different market price. To serve these multiple purposes a slide rule has been developed, which solves these equations in different directions.

14.- A SLIDE RULE in it's common form, is an instrument which performs only additions and substractions of function values. These functions are expressed in length units along the scales. Each scale represents in fact a function table: the argument is written in figures, the function value is given in, for example, millimeters. A slide rule which solves the equation a.b=c , calculates the result by the addition log a + log b = log c . The three scales represent the functions log a, log b and log c. The arguments a,b and c are written in figures and the function values are given in millimeters from the points f[x]= 0, after multiplication with a millimeters/function unit value.

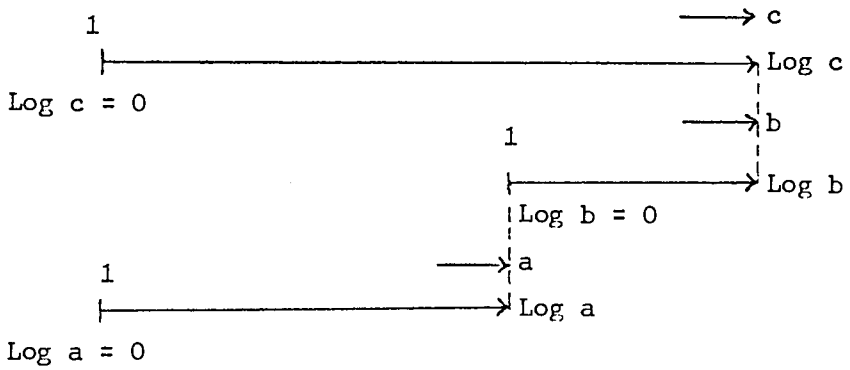

Fig. 1

It is easy to see that the scales for (c, log c) and (a, log a) are identical and fixed to the same place. So the actual slide rule may be reduced to a simplified type:

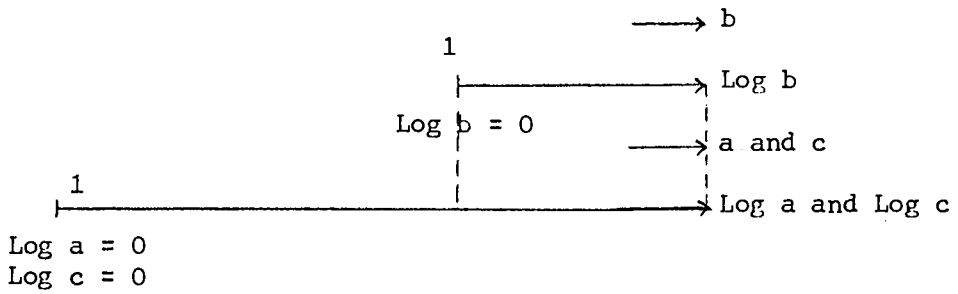

Fig. 2

This type of operation and some other actions may simplify the physical construction of an abacus, as will also be illustrated by the design of the geochemical slide rule.

15.- THE GEOCHEMICAL SLIDE RULE solves firstly the equation (14). The expression can be written in the additive form by applying the logarithmes:

$$\log \alpha = \log \frac{100}{6} - \log \left[ERF^{-1} \left[1 - \frac{2r}{R} \right] \right]^2 - \log \left[\log \frac{D}{d} \right] + \log \left[\log^2 \frac{x_k}{\gamma_R} \right] \qquad [16]$$

To adjust the necessary scale parts around the setpoints (where the function value is zero), the equation (16) may also be written:

$$\log \frac{\alpha.6}{100} = - \log \left[ERF^{-1} \left[1 - \frac{2r}{R} \right] \right]^2 - \log \left[\log \frac{D}{d} \right] + \log \left[\log^2 \frac{x_k}{\gamma_R} \right] \qquad [17]$$

or:

$$f_4[\alpha] = f_1\left[\frac{r}{R}\right] + f_2\left[\frac{D}{d}\right] + f_3\left[\frac{x_k}{\gamma_R}\right] \qquad [18]$$

An abacus may now be constructed according to the scheme:

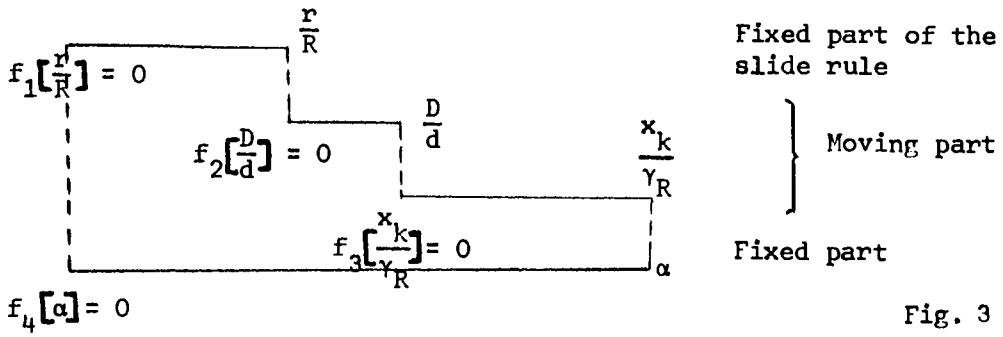

Fig. 3

The calculation of α at given $\frac{r}{R}$, $\frac{D}{d}$ and $\frac{x_k}{\gamma_R}$ asks, in this case, for the actions:

1. move the window slide (w.s.) on the $\frac{r}{R}$ value
2. move the central slide (c.s.) until the $\frac{D}{d}$ setpoint is under the marker
3. move the w.s. to the $\frac{D}{d}$ value
4. move the c.s. until the $\frac{x_k}{\gamma_R}$ setpoint is under the marker

5. move the w.s. to the $\frac{x_k}{\gamma_R}$ value

6. read the value for α .

This scheme is rather complicated. The case may be simplified by calculating:

$$f_4[\alpha] = f_1\left[\frac{r}{R}\right] + \left[f_2\left[\frac{D}{d}\right] + f_3\left[\frac{x_k}{\gamma_R}\right]\right] \qquad [19]$$

In terms of slide rule scales this means: represent the sum of the second and the third term as one distance. This is actually performed by choosing the positive direction of $f_2\left[\frac{D}{d}\right]$ opposite to the positive direction of $f_3\left[\frac{x_k}{\gamma_R}\right]$ and letting the zero points of the function coincide:

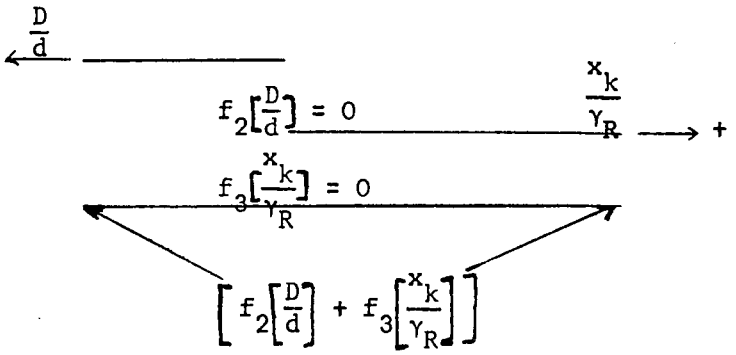

Fig. 4

The scales for $\left[\frac{D}{d}\ ,\ f_2\left[\frac{D}{d}\right]\right]$ and $\left[\frac{x_k}{\gamma_R}\ ,\ f_3\left[\frac{x_k}{\gamma_R}\right]\right]$ are fixed to each other which means that after choosing the right places we may forget about the actual places of the zero points: only the values $\frac{D}{d}$ and $\frac{x_k}{\gamma_R}$ are of importance.
Until here, only positive values of the functions have been considered. It is easy to see that the schemes and description do not change for incidental negative function values.
By applying the simplification of expression (19) and fig.4, the scheme of the geochemical slide rule becomes:

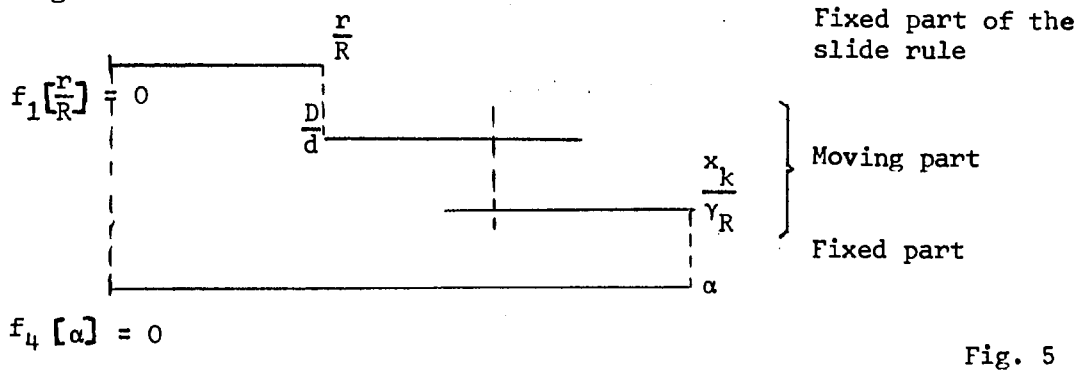

Fig. 5

The manipulations to calculate α at given $\frac{r}{R}$, $\frac{D}{d}$ and $\frac{x_k}{\gamma_R}$ are now:

1. move the w.s. to the $\frac{r}{R}$ value
2. move the c.s. until the value of $\frac{D}{d}$ under the marker
3. move the w.s. to the $\frac{x_k}{\gamma_R}$ value
4. read the α value

It is clear that also the zero points of the $\left[\frac{r}{R}\ ,\ f_1\left[\frac{r}{R}\right]\right]$ and the $\left[\alpha,\ f_4[\alpha]\right]$ scale are not used anymore when the scales are properly positioned.
In the examples α is taken as the dependent variable. But each of the four variables may be calculated if the other three are given, in the same simple way.
The next functions have been calculated by a small computer program:

$$f_1\left[\frac{r}{R}\right] = -\log\left[ERF^{-1}\left[1 - \frac{2r}{R}\right]\right]^2 \cdot m \qquad [20]$$

$$f_2\left[\frac{D}{d}\right] = -\left[-\log\left[\log \frac{D}{d}\right] \cdot m\right] \quad \text{positive direction to the left} \qquad [21]$$

$$f_3\left[\frac{x_k}{\gamma_R}\right] = \log\left[\log^2 \frac{x_k}{\gamma_R}\right] \cdot m \qquad [22]$$

$$f_4[\alpha] = \log\left[\frac{\alpha.6}{100}\right] \cdot m \qquad [23]$$

in which m is the millimeters per function unit factor which estimates also the final length of the slide rule. For each scale division mark the functions must be calculated.

16.- <u>THE GEOCHEMICAL SLIDE RULE</u> solves also the equation (15). The additive form of this expression is:

$$\log\left[\log \frac{\bar{x}}{\gamma_R}\right] = \log 0.015 + \log \alpha + \log\left[\log \frac{D}{d}\right] \qquad [24]$$

To apply the same scales and functions (21) and (23) as for the first abacus expression, the equation is written as:

$$\log\left[\log \frac{\bar{x}}{\gamma_R}\right] - \log\left[\frac{100*0.015}{6}\right] = \log \frac{\alpha.6}{100} + \log\left[\log \frac{D}{d}\right] \qquad [25]$$

The geochemical slide rule could be extended by the scale:

$$f_5\left[\frac{\bar{x}}{\gamma_R}\right] = \left[\log\left[\log \frac{\bar{x}}{\gamma_R}\right] - \log 0.25\right].m \qquad [26]$$

The actions for calculating the value of $\frac{\bar{x}}{\gamma_R}$ at given α and $\frac{D}{d}$ are:

1. move the w.s. marker on the α value
2. move the c.s. until the setpoint of the $\frac{D}{d}$ scale is under the marker
3. move the w.s. to the $\frac{D}{d}$ value
4. read the $\frac{\bar{x}}{\gamma_R}$ value.

Schematic representation:

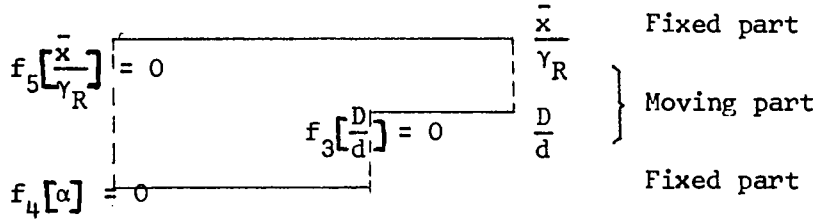

Fig. 6

However a numerical evaluation of the functions $f_1 \ldots f_5$, combined with the intervals of interest for each of the variables, showed that the scale for the function (26) asked for a lengthening of the slide rule to the right, compared with the scales for the first abacus expression. To avoid this a replacement factor Q has been introduced into the equation (25):

$$\log\left[\log \frac{\bar{x}}{\gamma_R}\right] + Q = \log \frac{\alpha.b}{100} + \log\left[\log \frac{D}{d}\right] + Q + \log 0.25 \qquad [27]$$

The functions (21) and (26) become respectively:

$$f_2'\left[\frac{D}{d}\right] = \left[\log\left[\log \frac{D}{d}\right] + Q + \log 0.25\right].m \qquad [28]$$

$$f_5'\left[\frac{\bar{x}}{\gamma_R}\right] = \left[\log\left[\log \frac{\bar{x}}{\gamma_R}\right] + Q\right].m \qquad [29]$$

The difference between the functions $f_2\left[\frac{D}{d}\right]$ and $f_2'\left[\frac{D}{d}\right]$ is only a matter of setpoint: the actual scales are the same for both functions. As for the first abacus expression it was not necessary to draw a setpoint for $\frac{D}{d}$ on the scale, the second setpoint (for the second abacus expression) will not cause problems.

Once the $\frac{\bar{x}}{\gamma_R}$ scale has been positioned properly, so that its setpoint coincides with the setpoint of the α-scale, the zero value mark is not needed anymore and consequently has not been drawn on the rule.

17.- THE GEOCHEMICAL SLIDERULE

The functions [20] - [23], [28] and [29] give the distance in millimeters from the zeropoints of the scales. For a total lenght of 29 cm. the values of the constants are:

$m = 42{,}0$ mm/function unit

$Q = -0{,}3589$

The reference points, which are not drawn on the scales as do not have a calculation function, are the points where the functionvalue is zero:

	SCALE	FUNCTION	VALUE OF ARGUMENT
1	$\frac{\bar{x}}{\gamma_R}$	$f_5'\left[\frac{\bar{x}}{\gamma_R}\right] = 0$	$\frac{\bar{x}}{\gamma_R} = 4.188$
2	$\frac{r}{R}$	$f_1\left[\frac{r}{R}\right] = 0$	$\frac{r}{R} = 7.864 \times 10^{-2}$
3	α	$f_4[\alpha] = 0$	$\alpha = 16.67$
4	$\frac{d}{D}$	$f_2\left[\frac{D}{d}\right] = 0$	$\frac{d}{D} = 0.3679$
5	$\frac{x_k}{\gamma_R}$	$f_3\left[\frac{x_k}{\gamma_R}\right] = 0$	$\frac{x_k}{\gamma_R} = 2.7183$
6	$\frac{d}{D}$	$f_2'\left[\frac{D}{d}\right] = 0$	$\frac{d}{D} = 3.247 \times 10^{-2}$

The setpoints of the first three functions has to coincide on a vertical line on the body of the sliderule. The setpoints of the scales 4 and 5 has to coincide on the slide. Scales 4 and 6 are identical: only the setpoint for scale 6 has to be indicated. The actual construction of the sliderule has been chosen as such to enable the user to note additional marks on the scales.

18.- THE URANIUM RESERVES OF THE WORLD may be calculated as an example of the use of the geochemical slide rule.

Considering all the known U ore reserves, (see definition in paragraph 3) the median individual reserve is estimated as 4000 tons U at a median content of 1500 PPM. The total known reserves of this quality contain about 500.000 tons U. The dimensions ratios of the average deposit are b/a = 0.5 and c/b = 0.1. The specific gravity of the ore is about the same as for the earth's crust: 2.7. These information represent in fact an extreme part of the distribution curve for U in the earth's crust as environment.

Combined with the data for the whole crust one may calculate the distribution curves for different deposit sizes. These data are: the dry land surface is $1.5 * 10^8$ km^2. Taking into consideration a depth of the crust of 2.5 km, the weight of the environment can be estimated as 10^{18} tons. The dimension ratios are taken as b/a = 1 and c/b = 0. The mean content of U is also known:

$$\bar{x} = 3 \text{ PPM} \qquad \text{(Green 1959).}$$

Collecting the data:

$$\frac{r}{R} = \frac{500.000 * \frac{100}{0.15}}{10^{18}} = 3.3 * 10^{-10} \qquad [31]$$

$$a = \sqrt[3]{\frac{4000 * \frac{100}{0.15} * 10^{-9} * \frac{1}{2.7}}{0.5^2 * 0.1}} = 0.34 \text{ km} \quad \text{(see expr. [10])} \quad [32]$$

$$d = 0.34\left[1+0.5+0.05\right] = 0.53 \text{ km} \quad \text{(see expr. [11])} \quad [33]$$

$$D = \sqrt{\frac{150 * 10^6}{1}} * \left[1+1\right] = 24400 \text{ km} \quad \text{(see expr. [13])} \quad [34]$$

$$\frac{d}{D} = 2.2 * 10^{-5} \qquad [35]$$

$$x_k = 1500 \text{ PPM} \qquad [36]$$

$$\bar{x} = 3 \text{ PPM} \qquad [37]$$

The first goal is now to solve α with expression (14). Here we are confronted with a shortcoming of the slide rule. Because the abacus cannot directly calculate the value of α with this configuration of given data. The problem is that $\bar{x}$ is given and not γ_R. However, this difficulty will be solved in future by directly presenting a list of α-values and $\bar{x}$-values for the most

important elements as these values are fixed constants for the earth's crust as environment.

For the moment, γ_R will be calculated by a slide rule iteration. Assume first $\gamma_R = \bar{x} = 3$ PPM, then $\frac{x_k}{\gamma_R} = 500$. With (31) and (35), this gives $\alpha = 3.15\%$. Again using the value (35) we find $\frac{\bar{x}}{\gamma_R} = 1.65$ or $\bar{x} = 5$ PPM. This value is too high, so the calculation is repeated with $\gamma_R = \frac{3}{5} * 3 = 1.8$ PPM, thus $\frac{x_k}{\gamma_R} = 830$ which gives $\alpha = 3.6\%$ and $\bar{x} = 3.2$ PPM. Final estimation gives $\alpha = 3.8\%$, $\gamma_R = 1.63$ PPM, $\bar{x} = 3$ PPM. Now we will consider all the deposits with an average of 3.000.000 tons U ore and calculate the quantity of uranium of different grades.

The fixed values for this curve are:

$$\alpha = 3.8\% \ , \ \frac{d}{D} = 2.2 * 10^{-5} \ , \ \bar{x} = 3 \text{ PPM and } \gamma_R = 1.63 \text{ PPM} \qquad [38]$$

The next table may be calculated with the geochemical slide rule

Deposit with an average of 3.000.000 tons ore					
Grade in PPM			tons ore	tons U	Number of deposits
500	307	1.12×10^{-7}	1.12×10^{11}	5.6×10^{7}	37000
1000	613	3.54×10^{-9}	3.54×10^{9}	3.5×10^{6}	1200
1500	920	3.39×10^{-10}	3.39×10^{8}	5.0×10^{5}	110
2000	1227	6.23×10^{-11}	6.23×10^{7}	1.2×10^{5}	20
3000	1840	5.20×10^{-12}	5.20×10^{6}	1.5×10^{3}	1
10000	6135	1.92×10^{-15}	1.92×10^{3}	-	-

(Table 1)

The lower grade deposits in this table contain all the higher grade ones. The table shows that our world is too small to find an U ore deposit of 3.000.000 tons ore with a content of 1% Uranium.

It is clear that the total amount of U contained in a deposit of this median size decreases with the lowering of the grade. To consider such lower-grade

resources as potential reserves the opposite would be required.
Starting from the median size ore reserve of about 3.000.000 tons ore with a grade of 1500 PPM U and stating that a potential reserve with a grade of 2/3 times the median ore grade should contain at least 2.5 times the amount of Uranium and using these factors for each lower grade potential reserves, the next table can be calculated:

Potential Uranium Reserves									
Grade x_k in PPM	Tons U	d KM	$\frac{d}{D}$	$\frac{\bar{x}}{\gamma_R}$	γ_R PPM	$\frac{x_k}{\gamma_R}$	$\frac{r}{R}$	r	Total tons U
1500	4000	0.53	$2.2\text{x}10^{-5}$	1.85	1.62	926	$3.2\text{x}10^{-10}$	$3.2\text{x}10^{8}$	$5\text{x}10^{5}$
1000	10000	0.82	$3.7\text{x}10^{-5}$	1.80	1.67	599	$1.9\text{x}10^{-9}$	$1.9\text{x}10^{9}$	$2\text{x}10^{6}$
670	25000	1.28	$5.2\text{x}10^{-5}$	1.76	1.76	394	$9.5\text{x}10^{-9}$	$9.5\text{x}10^{9}$	$4\text{x}10^{6}$
440	62500	1.99	$8.2\text{x}10^{-5}$	1.71	1.75	251	$5.0\text{x}10^{-8}$	$5.0\text{x}10^{10}$	$2\text{x}10^{7}$
300	156250	3.06	$1.3\text{x}10^{-4}$	1.67	1.80	167	$2.1\text{x}10^{-7}$	$2.1\text{x}10^{11}$	$6\text{x}10^{7}$

(Table 2)

Each estimated resource includes all resources of a higher content.

19.- GEOCHEMICAL SURVEYS AND PROSPECT EVALUATION is a second interesting field in which the slide rule might be applied. It may be calculated, with the given survey results $\bar{x}$ and α, whether or not an ore deposit of average size and grade can be expected to occur in the sampled environment.
Considering the expressions (6) and (7), r_k gives the total tons of ore, occurring in an environment R, with a grade x_k in deposits of size $\bar{w}$. One of these deposits will have the highest grade: x_{max}. The value of x_{max} may be solved by:

$$r_{max} = \bar{w} \qquad [39]$$

$$P_{max} = \frac{r_{max}}{R} \qquad [40]$$

Together with α and $\frac{d}{D}$ the slide rule gives a value for $\frac{x_{max}}{\gamma_R}$ and as γ_R is known, according to paragraph 17, x_{max} may be calculated. This procedure may also be performed for deposits of other weights than $\bar{w}$, reminding that

with changing the size the γ_R changes also. Thus we may calculate for a geochemical survey the grade of the richest possible ore deposit with a size equal to the average ore deposit in the earth crust. If the x_{max} of this potential deposit is larger than the x_k of the average ore deposit, the area may be considered favorable.

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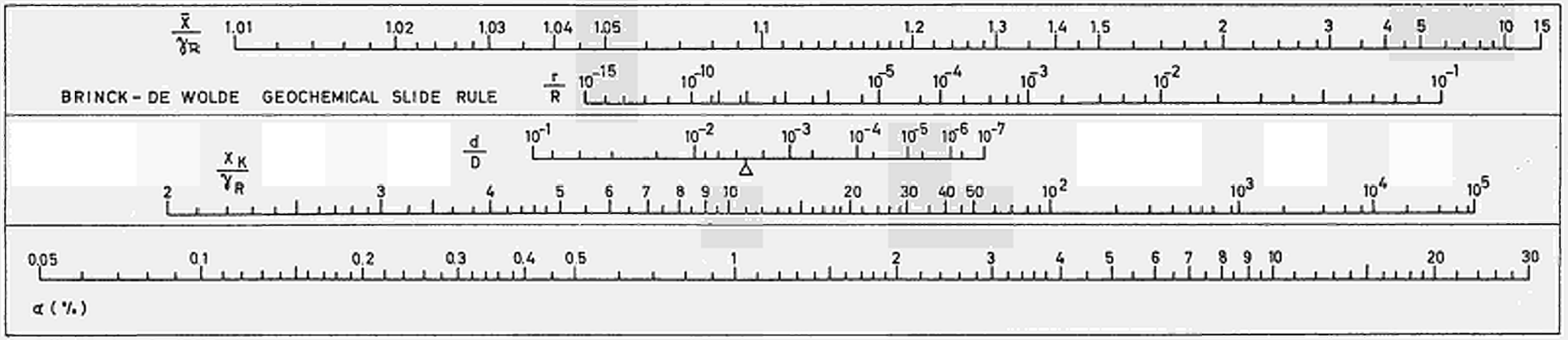
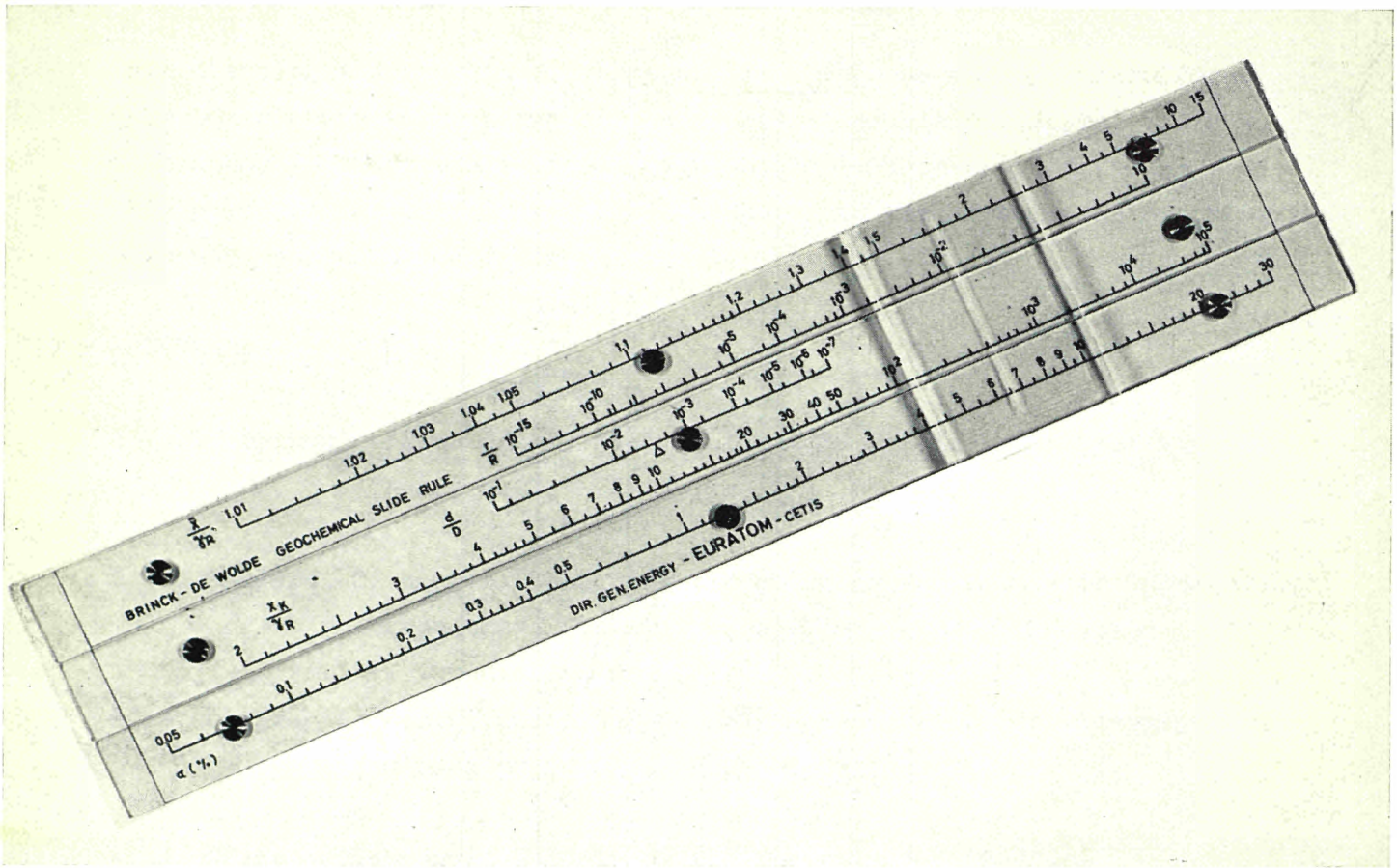
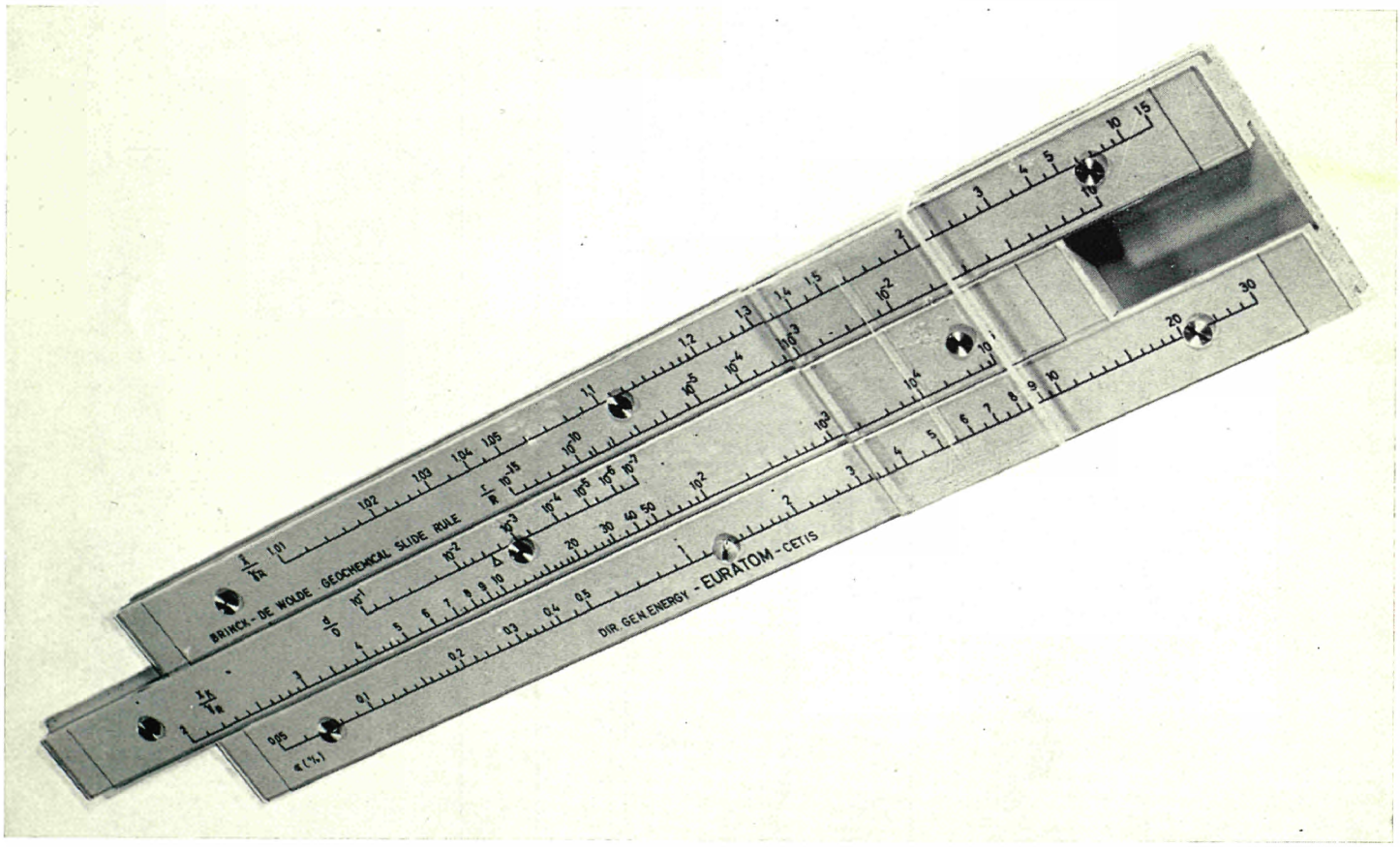

$\frac{\bar{X}}{\gamma_R}$ 1.01 1.02 1.03 1.04 1.05 1.1 1.2 1.3 1.4 1.5 2 3 4 5 10 15
BRINCK - DE WOLDE GEOCHEMICAL SLIDE RULE
$\frac{r}{R}$ 10^{-15} 10^{-10} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1}
$\frac{d}{D}$ 10^{-1} 10^{-2} 10^{-3} 10^{-4} 10^{-5} 10^{-6} 10^{-7}
$\frac{X_K}{\gamma_R}$ 2 3 4 5 6 7 8 9 10 20 30 40 50 10^2 10^3 10^4 10^5
0.05 0.1 0.2 0.3 0.4 0.5 1 2 3 4 5 6 7 8 9 10 20 30
α (%)





FOTOGRAPHS OF THE SLIDE RULE

To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.

Alfred Nobel

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